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## Chemical Reactions in Turbulent Mixing Flows

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Air Force Office of Scientific Research  
Grant No. 90-0304

Final Technical Report Supplement: Period ending 31 December 1992

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30 June 1993

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 30 June 1993	3. REPORT TYPE AND DATES COVERED Supplement--15 May 92 thru 30 Dec 92		
4. TITLE AND SUBTITLE  Chemical Reactions in Turbulent Mixing Flows (u)		5. FUNDING NUMBERS  PE - 61102F PR - 2308 SA - BS G - AFOSR-90-0304		
6. AUTHOR(S) Paul E. Dimotakis James E. Broadwell Anthony Leonard		7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  California Institute of Technology Graduate Aeronautical Laboratories Mail Stop 301-46 Pasadena, CA 91125		
8. PERFORMING ORGANIZATION REPORT NUMBER  AFOSR-TR-93 (243) 0612		9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NA Building 410 Bolling AFB DC 20332-6448		
10. SPONSORING/MONITORING AGENCY REPORT NUMBER		11. SUPPLEMENTARY NOTES		
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words)  This is a supplement to the Final Annual Report for this Grant. It documents: (i) an upgrade/modification to the Supersonic Shear Layer (S <sup>3</sup> L) combustion facility, and (ii) progress and developments in digital-image-data systems and acquisition, realized during the no-cost extension period, ending 30 June 1992.				
14. SUBJECT TERMS  Shear Layers, Mixing, Combustion, Digital Image Systems		15. NUMBER OF PAGES 9		
16. PRICE CODE		17. SECURITY CLASSIFICATION OF REPORT Unclassified		
18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT UL

### Abstract

This is a supplement to the Final Annual Report (Dimotakis, Broadwell, & Leonard 1992), for the period ending 14 May 1992. It documents:

- an upgrade/modification to the Supersonic Shear Layer (S<sup>3</sup>L) combustion facility

and

- progress in image-data acquisition,

realized during the no-cost extension period, ending 31 December 1992, of AFOSR Grant No. 90-0304.

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## 1. Introduction

This report is issued as a supplement to the Final Annual Report for the period ending 14 May 1992, of AFOSR Grant No. 90-0304(Dimotakis, Broadwell, & Leonard 1992). It documents progress realized during the no-cost-extension period, ending 31 December 1992. Specifically, it discusses work performed to modify the the Supersonic Shear Layer ( $S^3L$ ) combustion facility test section, as well as upgrade the image-data acquisition capabilities developed under the sponsorship of this Grant.

## 2. Supersonic Shear Layer Combustion Facility

This part of the effort was undertaken to address two deficiencies in our Supersonic Shear Layer ( $S^3L$ ) combustion facility (see Hall and Dimotakis 1989): the run-time noise level and the ingestion of exhaust-duct gases, and NaOH-droplet spray, into the test-section following the end of a run.

The noise level of the sound generated in the course of a 2 – 3 s run in the Supersonic Shear Layer facility is quite high. The level for a typical (high-speed stream) Mach 1.5 run is measured to be about 120 dB in the lab. Similar levels are radiated outside the lab. As the facility is in the middle of the Caltech campus, the sound level needs to be reduced, especially in anticipation of higher Mach number runs in the next twelve months. It does not only represent a disruptive nuisance but is also a safety hazard; it starts abruptly and can startle unwarned personnel who might be working with dangerous equipment in the vicinity.

A major source for the sound is the jet formed as the supersonic high speed stream exits into the exhaust duct. There are several ways to reduce this noise; one is to try to break up the supersonic jet, the other is to absorb the sound in the tunnel with a spray of water droplets. The latter is easier because the facility is equipped with showers enabling neutralization of HF (product of reacting runs) with a water-NaOH solution. Water alone can be sprayed through the showers in non-reacting runs, reducing sound levels by over 5 dB.

There is another problem associated with the showers. During the run, the supersonic stream entrains gas from the test section, acting as a jet pump. The pressure in the test section is reduced to about 80 % of atmospheric. At the end of the run, this pressure is recovered by ingesting gas from the exhaust tunnel. If the

showers are running, this also brings the water or water-NaOH droplets back into the test section. Either case is unacceptable when experiments are run with optics in the test section. This has the effect of limiting the optical runs (such as planar laser-Rayleigh scattering) to nonreacting runs that are run without showers.



FIG. 1 Photograph (CCD image) of diffuser-screen assembly.

In an effort to address these problems, a specially-designed diffuser screen assembly was fabricated (see Fig. 1). The intent was to both break up the jet and introduce a pressure drop from the test section into the exhaust, thus creating higher pressure in the test section. This higher pressure would reduce the back-flow at the end of the run, and reduce the shower problems.

One of the primary design drivers and considerations was safety. Although the screen had to be able to withstand dynamic loads imposed by the supersonic stream, it needed to yield if something obstructed the exit. If the screen were to not fail when the exit was obstructed, the pressure limit for the test section could be exceeded. To avoid this, the screen is designed mounted on a frame extending from the test section into the exhaust duct. Although the frame is made of welded stainless steel, the screen itself is attached to the frame by a small number stainless steel wires. This allows the screen to withstand operating stresses but fail by breaking free of the frame if the stresses rise above those anticipated as a result of normal operating flow conditions high (*i.e.*, if the screen is blocked). A diagram of the position of the screen in the test section is shown in Fig. 2.

The screen works well in reducing noise. The diffuser action of the screen slows and breaks up the supersonic jet as it enters the exhaust tunnel. The noise levels have reduced considerably. We are also designing a warning siren, that would emit an easily-recognized sound, to warn people in the vicinity that a short-duration, loud noise will follow in a few seconds.

However, the screen works better as a diffuser than as a pressure-dropping screen. Specifically, the pressure drop across the screen is less than the pressure rise due to the slowing of the supersonic flow and, as a consequence, the pressure in the test section is actually lower with the screen in place. We will continue to study this problem and hope to address it before proceeding to higher Mach numbers, as part of the on-going effort in this area.

BISONIC SHEAR LAYER TEST SECTION: FOUR-VIEW ASSEMBLY DRAWING

APPROX. SCALE: 1/8" = 1" INCHES

STREAMWISE CROSS-SECTION

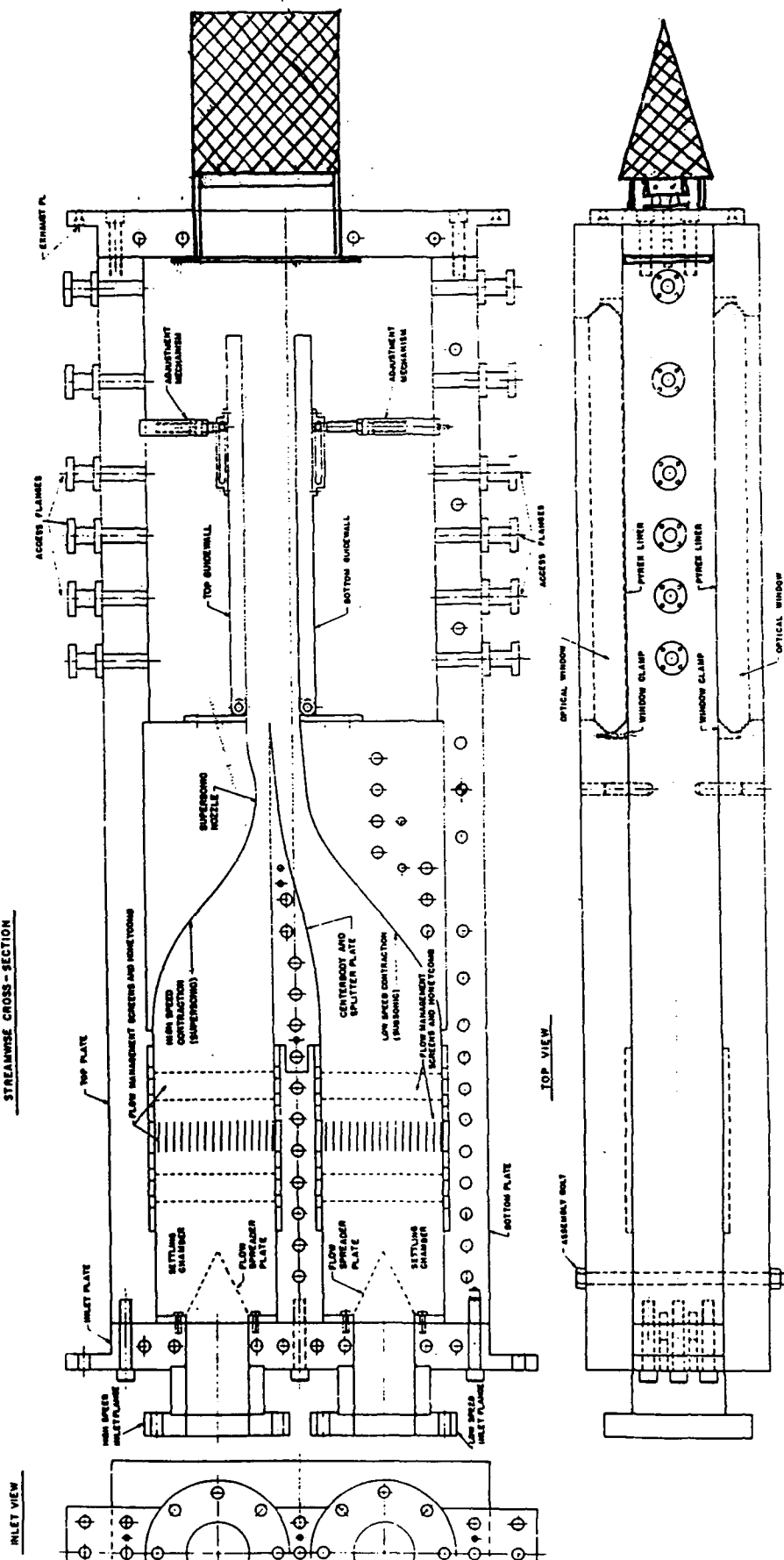


Fig. 2 Schematic of Supersonic Shear Layer facility test section and screen position.

### 3. Diagnostics, Instrumentation, & Experimental Techniques

We have decided to invest considerable effort in developing high resolution, high signal-to-noise ratio, and high framing-rate digital imaging techniques (these three specifications are typically in conflict and must be traded-off against each other). This requirement is driven by the need for many types of measurements in both supersonic and subsonic flows.

Unfortunately, commercial equipment is typically limited in terms of these criteria, especially in combination, as well as being relatively inflexible in accommodating custom CCD designs as well as CCD usage that may be a little out of the ordinary (partial readout, variable clocking schemes, multiple-phase clocks, etc.). Many of our experimental applications that are dictated by the research effort are best implemented with out-of-the ordinary use of these imaging devices. As has often occurred in the past, the limited commercial application of some of these methods, *at any one time*, has forced us to move ahead of commercially-available technology.

We now find ourselves in a similar junction with respect to digital-imaging technology and have decided to undertake a customized, flexible system that accommodate the range of CCD-based devices we would like to employ. Specifically, in addition to the on-going development of high-speed digital-data-acquisition systems, an effort has begun to design and fabricate microprogrammable timing logic controllers that can handle the wide range of CCD devices also under development in collaboration with the Jet Propulsion Laboratory, under joint sponsorship of this program and ARPA/ONR Contract No. N00014-91-J-1968. This effort is presently in progress. By way of illustration, the "photo" of the exhaust screen that was installed in the Supersonic Shear Layer Combustion facility test section (Fig. 1), was captured on a cryogenically-cooled CCD, transferred to the computer, and printed as a postscript file for this report.

We expect to document these developments, as well as the features and specifications of the resulting electronic instrumentation, in subsequent progress reports and publications.



#### 4. References

DIMOTAKIS, P. E., BROADWELL, J. E. & LEONARD, A. 1992 "Chemical Reactions in Turbulent Mixing Flows," California Institute of Technology, AFOSR-90-0304 Final Technical Report.

HALL, J. & DIMOTAKIS, P. E. 1989 "Design Overview of the Supersonic Hydrogen-Fluorine Facility (V4.0)," GALCIT Internal Report, 30 August 1989 (available from the authors on request).